U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: SUBSTANTIATING FLOW RATES AND PRESSURES IN FUEL SYSTEMS OF SMALL AIRPLANES

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Change:

1. PURPOSE. This advisory circular (AC) provides information and guidance concerning an acceptable means, but not the only means, of compliance with Part 04a and Part 3 of the Civil Air Regulations (CAR) and Part 23 of the Federal Aviation Regulations (FAR) applicable to substantiating fuel flow rates and pressures in fuel systems of reciprocating and turbine-powered small airplanes. In lieu of following this method, the applicant may elect to establish an alternate method of compliance that is acceptable to the Federal Aviation Administration (FAA) for complying with the noted regulations. This material is neither mandatory nor regulatory in nature and does not constitute a regulation.

2. RELATED REGULATIONS. Section 23.955 of Part 23 of the FAR; sections 3.433 of Part 3 and 04a.625 of Part 04a of the CAR.

3. BACKGROUND. Fuel flow characteristics are normally demonstrated with the entire fuel system installed in the airplane during the airplane type certification program when showing compliance with the FARs and engine requirements. The capability of the fuel system to provide sufficient flow is determined and separate flow investigations of each system component are avoided. At some later time, owners may petition to modify their airplanes in such a way as to have a major effect on the originally-approved fuel system. This normally requires reconducting the fuel flow tests in order to substantiate continued compliance of the fuel system with applicable regulations and engine manufacturer's requirements. Fuels of the physical properties and octane rating to be used in service should flow at not less than the rate specified by regulation and at the pressure established in compliance with section 33.7. Test conditions, such as critical airplane attitude and, when pertinent, the pressure differential between the fuel tank airspace and carburetor float bowl airspace, are equally important to the demonstration. A suitable mock-up of the fuel system can be used to demonstrate fuel flow capacity.

4. TEST CONDITIONS.

a. Critical Airplane Attitude. Conventional tractor-propeller-driven airplanes normally have fuel tanks aft of the carburetor or engine injector inlet. For this reason, conditions grow less favorable for fuel flow the further the airplane is rotated in the "nose-up" attitude. Likewise, for pusher-propeller-driven airplanes, normally having the fuel tanks forward of the carburetor or engine injector inlet, conditions grow less favorable for fuel flow the further the airplane is rotated in "nose-down" attitude. To determine the critical attitude for tractor type airplanes in which the flow tests are to be conducted, information is necessary concerning the attitude of the airplane with respect to the ground while flying at best angle of climb with takeoff power or critical attitude at minimum weight. An exception to this, as noted above, would be the pusher propeller airplane, where the critical attitude would likely be a "nose-down" flight condition. The critical attitude may be determined with the use of an inclinometer by flying the airplane before and after modification at critical weight with takeoff power at best angle of climb airspeed.

b. Fuel System Pressure Differential. A pressure differential normally exists between the fuel tank airspace and the carburetor float bowl airspace at various climb attitudes and climb speeds. This pressure differential is caused by the ram air pressure increase in the fuel tank during flight and the suction within the carburetor caused by air movement over the engine carburetor venturi. One method to determine the fuel system pressure differential to be used in calculating the minimum fuel head for conducting fuel flow tests is as follows:

(1) Connect a calibrated airspeed indicator between the fuel tank vent airspace and the carburetor float bowl airspace as shown in the schematic drawing (see figure 1). The pitot pressure connection of the indicator should be connected to the fuel tank vent airspace and the static connection to the carburetor float bowl airspace. A liquid trap should be placed on each side of the airspeed indicator to assure that any liquid that enters the pressure line does not affect airspeed reading. The carburetor float bowl should be vented to the atmosphere at the normal carburetor air passage during the test.

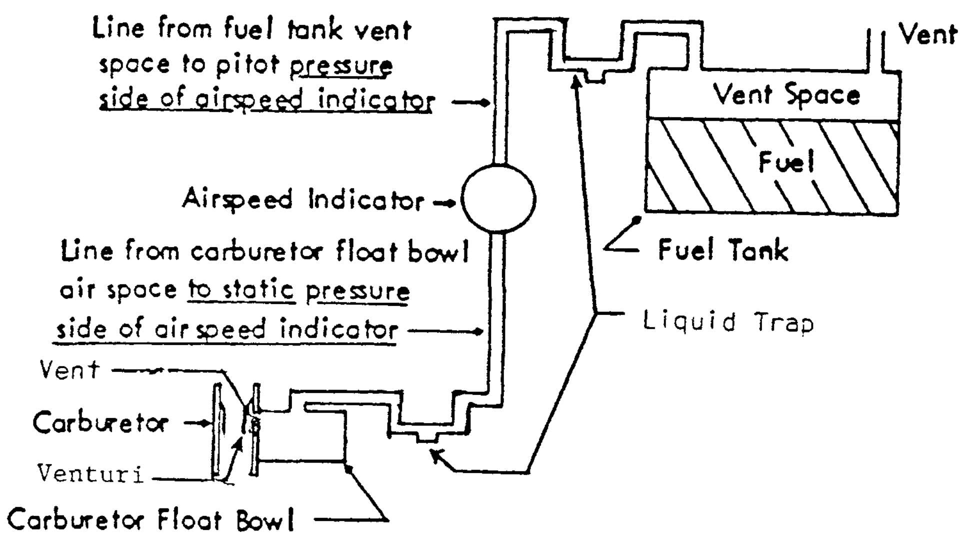

FIGURE 1. FUEL SYSTEM PRESSURE DIFFERENTIAL -- AIRSPEED

(2) With the airspeed indicator installed as described above, fly the airplane at best angle of climb airspeed, (V_x), carburetor inlet air heat off, full rich mixture, if mixture is controllable, and critical weight. Record the airspeed indicated on the instrument connected between the fuel tank and carburetor when the airplane's regular airspeed indicator shows the airplane to be flying at V_x.

(3) Calculate the pressure differential, ΔH, between the fuel tank vent airspace and the carburetor float bowl using the following equation:

$$\Delta H = 6.81 \left(\frac{V}{100}\right)^2$$

Where Δ H = Pressure differential in inches of fuel.
V = Airspeed indicator reading in miles per hour.

The ΔH obtained may be subtracted from the minimum carburetor inlet pressure specified by the engine manufacturer to determine the minimum pressure to be substantiated by the fuel flow tests.

(4) A U-tube manometer (see figure 2) containing actual fuel or any other appropriate fluid may be used in lieu of the airspeed indicator to determine the pressure differential. Use of fuel in the manometer will allow reading pressure differential directly in inches of fuel. If some other fluid is used, the differential height must be corrected for specific gravity of the test fluid. A U-tube manometer is generally commercially available or can be constructed of clear plastic or glass tubing. Installation of a U-tube manometer containing fuel in the cabin can be very hazardous; therefore, special precautions should be taken to prevent damage or spillage, or to incorporate provisions to collect and drain any fuel spillage overboard.

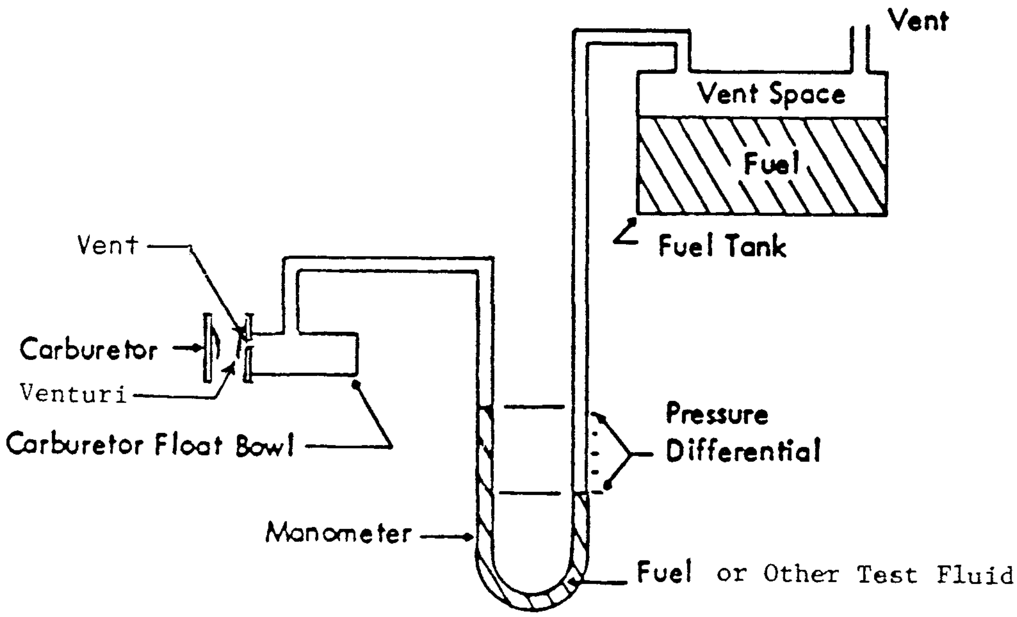

FIGURE 2. FUEL SYSTEM PRESSURE DIFFERENTIAL -- U-TUBE MANOMETER

c. Minimum Inlet Pressure. The engine manufacturer, in most cases, establishes the minimum and maximum fuel pressure limits necessary to obtain satisfactory engine operation. These limits are shown on the applicable FAA Engine Type Certificate Data Sheet (TCDS) or Specification. The fuel pressure limits are shown in a number of different ways; i.e., minus or plus "x" pounds per square inch (psi), "y" psi above true vapor pressure of fuel, "z" inch fuel head differential between carburetor fuel inlet fitting and float bowl chamber. Most of these inlet pressure limits require no conversions. Some turbine engine manufacturers specify the minimum inlet fuel pressure as "x" psi above the true vapor pressure of the fuel used with a vapor/liquid (V/L) ratio of zero or that the maximum V/L ratio for emergency use should not exceed a specific value. These fuel pressure limits will require an analysis of the fuel to determine the maximum true vapor pressure of the fuel with the corresponding V/L. Alternatively, a suitable laboratory test may be conducted to determine the engine minimum fuel inlet pressure.

d. Supercharged Engine Fuel System Inlet Presure. The fuel pressure required at the carburetor or injector inlet is generally stated on the TCDS as a certain number of pounds per square inch above the inlet air pressure. The inlet air pressure for takeoff power is given in inches of mercury (H_g), and is converted to psi for computing the carburetor or injector inlet fuel pressure minimum limit. Since the supercharger, either mechanical or turbo, is capable of maintaining a fairly constant deck, or inlet air pressure, up to the critical engine altitude while fuel tank pressure decreases with increased altitude, the difference between the fuel tank pressure and the inlet air pressure is greatest at the critical altitude. Therefore, any pressure and flow tests conducted at a pressure altitude lower than the critical altitude should take into account the difference between the tank pressures at the actual test altitude and the critical altitude. This may be done by reducing the fuel tank pressure to the critical altitude pressure or by adding the difference to the pressure which the engine TCDS indicates the pump is required to deliver to the carburetor or injector.

e. Method to Determine Minimum Inlet Fuel Pressure for Reciprocating Engine. Should the minimum carburetor or injector inlet fuel pressure figure not be listed or available from the carburetor manufacturer, the following method may be used to determine an acceptable inlet pressure:

(1) Connect a gravity flow fuel tank that can be varied in height in relation to the carburetor inlet. Large tubing may be used to minimize the effects of fluid friction.

(2) With the airplane in the ground attitude, run the engine at full takeoff r.p.m. and manifold pressure. A propeller that will allow full takeoff r.p.m. and satisfactorily cool the engine should be used.

(3) Start with the fuel tank high enough to permit proper operation of the engine. Vary the fuel level by lowering the tank until the first evidence of engine malfunction occurs, then measure and record the fuel head available to the engine. This measurement is to be made from the carburetor fuel inlet to the top of the fuel level in the tank.

(4) Engine malfunction may be detected by use of an exhaust gas temperature indicator which will indicate change in the fuel air mixture. Any change in fuel air mixture will result in an exhaust gas temperature change and impending engine malfunction. Also, any noticeable change in engine r.p.m. or manifold pressure will indicate a change in engine horsepower.

(5) The measured fuel pressure at the inlet to the carburetor that will allow satisfactory engine operation plus a margin of 10 percent may be accepted as the established minimum inlet fuel pressure.

f. Special Considerations.

(1) If a fuel flowmeter is installed, block the flowmeter during the flow test and measure the fuel flow through the bypass per section 23.955(a)(2).

(2) If a fuel filter with bypass provisions are installed, block the fuel filter during the flow test and measure the fuel flow through the bypass.

(3) For turbine engines, the density of the fuel, the effects of low temperature, altitude, attitude, and water saturation should be evaluated.

5. TESTS.

a. Fuel Flow Rate for Gravity Feed Systems.

(1) Position the airplane on the ground with the thrust of fuselage level line at the most critical attitude for fuel flow. A bench test using the pertinent fuel system components located at relative elevations to represent actual airplane critical attitudes may be used. If the airplane is tested in the level flight attitude, determine by analysis and test the appropriate fuel head for the critical attitude and add this fuel head to the fuel system in the level flight attitude.

(2) The flow should be measured at the carburetor inlet and restricted at that point to the minimum operating pressure for a satisfactory takeoff power mixture as recommended by the carburetor and engine manufacturers. (If a reducing nipple is employed at the carburetor inlet, the flow should be measured through the nipple.) A satisfactory method of simulating the minimum pressure required at the carburetor inlet is to disconnect the fuel feedline at the carburetor and raise the end of the line an amount in inches equal to the required minimum operating pressure in inches of fuel. The required pressure is ascertained from the engine TCDS or the methods outlined in paragraphs 4.b. or 4.c. of this circular. The "differential pressure," calculated under paragraph 4.b. should be subtracted from the required minimum carburetor inlet pressure. For example, should the minimum permissible fuel inlet pressure turn out to be 19 inches of fuel and a pressure differential of 7 inches of fuel is produced between the fuel tank vent space and the carburetor float bowl airspace, then the test should be run with the fuel line assembly at the carburetor raised 12 inches above the fuel inlet fitting of the carburetor. The actual pressure available from a gravity system can be calculated at approximately one psi for each 40 inches head of fuel. Alternatively, compute the sum of the head pressure associated with best rate of

climb and carburetor inlet requirements, and demonstrate, with fuel restricted by a valve installed at the engine end of the system to simulate this pressure, that fuel flow is at least equal to the regulatory minimum.

(3) Prior to beginning the flow test, the fuel system should be completely drained. The system should be set to feed from one tank only. The flow should be tested with the fuel tank at the most critical position with respect to fuel flow. Fuel should be added to the tank slowly until a steady flow is established at the carburetor end of the feedline. Steady flow should be established when approximately the unusable fuel or low fuel supply has been added. When a steady flow has been established, an additional gallon of fuel, or the fuel quantity necessary to complete the flow test, should be added to the tank and the time in seconds recorded for at least one gallon of fuel to flow from the feedline. The time for one gallon of fuel to flow should not be more than the figure computed from the following:

(i) For reciprocating engine-powered airplanes certificated under Part 3 of the CAR or Part 23 of the FAR, at the rate of 150 percent of the actual takeoff fuel consumption of the engine, the equation is:

$$\text{Seconds per gallon} = \frac{14{,}400}{(\text{SFC})\ (\text{TOHP})}$$

Where: SFC = Specific fuel consumption of the engine expressed in pounds per hour for each takeoff horsepower.

TOHP = Takeoff horsepower of engine.

(ii) For reciprocating engine-powered airplanes certificated under Part 04a of the CAR, at the rate of double the normal flow required for takeoff engine power, the equation is:

$$\text{Seconds per gallon} = \frac{10{,}800}{(\text{SFC})\ (\text{TOHP})}$$

(iii) For turbine engine-powered airplanes under Part 23 of the FAR, at a rate of 100 percent of the actual takeoff fuel consumption of the engine, see paragraph 5.b.2(ii) for appropriate flow rate and limitations.

b. Fuel Flow Rate for Pump Feed Systems.

(1) Fuel flow rate tests for pump systems are conducted by placing the airplane in the same attitude as outlined in the procedure for gravity feed fuel system tests. Since, in this case, the fuel pump should be operated, it may be driven either by the engine with the pump mounted on the regular engine fuel pump drive pad or by a separate external power source. If it is desired to conduct the test with the pump mounted on the engine, a separate source of fuel external to the airplane is required to operate the engine at takeoff r.p.m. If an external power source is used to drive the fuel pump, the test should be conducted with the pump operating at the same speed as the pump operates when the engine is running at

takeoff r.p.m., and the pump mounted at the same height as it would be if mounted on the fuel pump pad on the engine. In either case, the pump discharge is collected and measured. A calibrated fuel flowmeter may be used to measure the actual fuel flow.

(2) Prior to beginning the test, the fuel system should be completely drained. The system should be set to feed from one tank only. Fuel is added to the tank slowly until a steady flow is established at the inlet to the carburetor or fuel injector unit. Steady flow should be established when approximately the unusable fuel supply has been added. When a steady flow has been established, an additional gallon of fuel should be added to the tank. The fuel flow tests should be made on the main fuel pump system followed by a test on the emergency fuel pump system with the main pump simulated failed or actually failed in the critical mode for fuel delivery.

(i) For reciprocating engine-powered airplanes certificated under Part 3 of the CAR or Part 23, amendment 6, of the FAR, the time for one gallon to flow should not be more than the lesser of the two figures computed from the following:

(A) At the rate of 0.9 pounds per hour for each takeoff horsepower:

$$\text{Seconds per gallon} = \frac{24{,}000}{\text{TOHP}}$$

(B) At the rate of 125 percent of the actual takeoff fuel consumption of the engine:

$$\text{Seconds per gallon} = \frac{17{,}300}{\text{(SFC) (TOHP)}}$$

(ii) For turbine-powered airplanes certificated under Part 23 of the FAR, at the rate of 100 percent fuel flow for each intended operation condition and maneuver, the time in seconds should not be more than the figure computed from the following:

$$\text{Seconds per gallon} = \frac{\begin{array}{c}\text{26,400 for JP-5 Fuel (Note)}\\ \text{23,400 for JP-4 Fuel (Note)}\end{array}}{\text{(SFC) (Hp or lbs. thrust, as applicable)}}$$

NOTE: Jet fuels vary in density at 60°F from 6.5 lbs./U.S. gallon for JP-4 to 6.95 lbs./U.S. gallon for JP-5. Since the flow rates for turbine-powered airplanes are 100 percent, the effects of cold fuel, blocked filters, altitude, attitude, maneuvers, acceleration, etc., should be included.

(iii) For reciprocating engine-powered airplanes certificated under Part 04a of the CAR, the time in seconds for one gallon of fuel to flow should not be more than the figure computed from the following:

$$\text{Seconds per gallon} = \frac{10{,}800}{\text{(SFC) (TOHP)}}$$

c. Fuel Flow Rate for Fuel Injection Pump System.

(1) A fuel injection system with an integral speed sensing pressure pump is normally capable of suction lift at the inlet to the pump; therefore, an emergency fuel pump may not be required. Fuel flow rate tests for fuel injector pump systems are conducted similarly to fuel flow rates for gravity feed systems, paragraph 5.a., with the following exceptions or additions:

(i) The fuel injector system normally has an engine-driven fuel injector pump that is approved as part of the engine. In this case, it is necessary to show that the fuel system, excluding the injector pump, complies with the applicable regulations. Therefore, any type fuel pump capable of providing the required flow capacity may be used to conduct the fuel flow tests. Pressure indicators installed in the fuel lines will be necessary to determine that the system will maintain the pressure specified by the engine manufacturer.

(ii) Some engine fuel injector systems have a bypass or return flow fuel system. These systems may be evaluated by determining that the system can conduct fuel back to the tank at the required flow rate without exceeding the back pressure established by the engine manufacturer at the bypass exit port.

(iii) When conducting the fuel flow test with a separate fuel pump, the fuel flow requirements of the main fuel system should include the quantity of fuel consumed by the engine plus the quantity returned to the fuel tank.

(2) Airplanes equipped with engine-driven integral speed sensing pressure pumps can experience engine failure when the optional emergency fuel pump produces a high output pressure. In these cases, the optional fuel pumps are not required by the regulation as emergency fuel pumps, but are used to supply fuel pressure at the engine-driven injector pump inlet for engine starting, vapor suppression and, in some cases, maintaining engine power after an engine-driven fuel injector pump failure. These optional pumps may have a sufficiently high fuel output pressure to adversely affect engine operation when the pump is turned on with the engine-driven pump operating normally. To ensure that the optional fuel pump operates within the maximum allowed fuel pressure limit at the inlet to engine-driven injector fuel pump, an inflight evaluation with both pumps operating, or a ground pressure check is recommended as follows:

(i) Block engine-driven fuel pump outlet line and operate the airplanes electric fuel pump under a no-flow condition.

(ii) Take pressure reading to ascertain that the fuel pressure falls within the pressure limits specified for the engine at the inlet to the fuel injector or compare the pump manufacturer's no-flow performance pressure with the injector pump's inlet limit.

d. Fuel System Component Changes. Changes in components such as an engine-driven fuel pump, or a wobble pump, can usually be substantiated by comparative tests of the components themselves without testing the entire airplane system. The replacement pump should be capable of delivering at least the same flow as the original pump when operating at the same suction lift and delivery pressure. The replacement pump should, of course, be operated at the same speed as the replaced pump for this determination. Care should be taken in comparing the replacement pumps to duplicate the flow and inlet and outlet pressure conditions of the installation.

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